Linear Distributed GaN MMIC Power Amplifier with Improved Power-added Efficiency

Jeong-sun Moon, Jongchan Kang, Dave Brown, Robert Grabar, Danny Wong, Helen Fung, Peter Chen, Dustin Le, Hwa Y. Tai, and Chuck McGuire

1) HRL Laboratories, 3011 Malibu Canyon Road, Malibu, CA 90265

Abstract: *We report on a multi-octave (100 MHz – 8 GHz), linear nonuniform distributed amplifier (NDPA) in a MMIC architecture using scaled 120-nm short-gate-length GaN HEMTs. The linear NDPAs were built with six sections in a nonuniform distributed amplifier approach, where each cell consists of main and g_{m3} cells. The small signal gain was >10 dB over the band, with saturated CW output power of ~35 dBm at Vdd = 17 V. The PAE improved by 7% – 10% within the band compared to the previous NDPA with 150-nm gate-length GaN FETs. Based on two-tone testing, the linear NDPA showed improved OIP3 of ~50 dBm, compared to OIP3 of 42 dBm for the NDPA without linearization. Under QPSK LTE waveform, the ACPR1improved by ~10 dBc at average output power of 23 dBm, without digital pre-distortion.*

Keywords: GaN, linear amplifiers, wideband amplifier, OIP3, LTE

Introduction

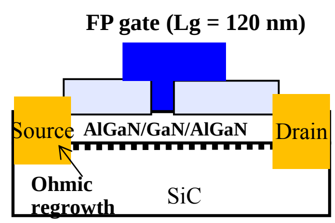
RF communications with spectral efficiency utilizes complex modulation schemes that require amplifier linearity [1]. GaN HEMTs have a high breakdown voltage that offers high output impedance and power density per input capacitance over GaAs PHEMTs. Over the last decade, various wideband GaN HEMT MMIC power amplifiers [2-7] and low-noise amplifiers [8-9] have demonstrated high dynamic range with an excellent output third-order intercept point (OIP3) of 40 to 52 dBm. However, for the high OIP3, these wideband GaN amplifiers exhibit an OIP3/Pdc ratio <5, and consume large amounts of DC power.

Especially in linear transmitters, several linearization techniques, such as feed-forward and pre-distortion, have been used to remove intermodulation products. For wideband and multi-octave linearization, analog pre-distortion has been introduced [10]. In general, these approaches increase the complexity of the RF system.

Current linearity/power-added-efficiency (PAE)/output power trade-offs impose a significant increase in an RF system's size, weight, and power (SWaP). In 2015, Moon et al., reported the first multi-octave (100 MHz – 8 GHz) GaN MMIC nonuniform distributed amplifier (NDPA) with built-in linearization and a g_{m3} cancellation method in class A and class C architectures [11]. Based on two-tone testing, the linear NDPA showed improved OIP3 of ~50 dBm, compared to OIP3 of 42 dBm for a NDPA without linearization. The resulting OIP3/Pdc was 16:1, which is the highest reported amongst GaN-based distributed amplifiers. The amplifier gain, however, was rather low. With P_{sat} of ~35 dBm, PAE of the linear NDPA was 40% – 12% over 100 MHz – 8 GHz bands. Challenges to improving PAE versus linearity in wideband amplifiers remain.

In this paper, we report on the measured CW performance of a multi-octave (100 MHz – 8 GHz) GaN MMIC NDPA fabricated with improved GaN HEMTs with a shorter gate length of 120 nm and peak RF gm of 480 mS/mm. The linear DPAs demonstrated improved gain of 10 – 12 dB. With P_{sat} of ~35 dBm, the PAE improved by 7% – 10% over 100 MHz – 8 GHz bands. The adjacent channel power ratio (ACPR1) under quadrature phase shift key (QPSK) long-term evolution (LTE) waveforms also improved by ~10 dBc at an average linear power of 23 dBm.

(a)



(b)

GaN HEMT	Prior Art	This work
Peak Ft (GHz)	52	60
Peak RF gm (mS/mm)	380	480
Cgs (pF/mm)	0.96	1.13
Cgd (pF/mm)	0.2	0.24
Pinch-off Voltage (V)	-3.2	-2.3

* Extracted from S-parameters at Vdd =10V, and peak gm bias

Figure 1. (a) A schematic drawing of ~120 nm gate length field-plate (FP) GaN HEMT is shown, (b) Modeled device parameters based on S-parameter measurements are summarized.

120nm Gate length field-plated GaN HFET

Figure 1(a) shows a schematic of a scaled 120-nm gate length field-plate (FP) GaN HEMT, where the FP GaN HFET was processed with ohmic regrowth instead of n+ GaN source contact ledge demonstrated in previous work [12]. The ohmic source-drain spacing was 3 µm. The on-state resistance was 1.6 Ω-mm. The maximum source-drain current (I_{max}) was 1.0 A/mm at Vds = 10 V. The table in Figure 1 summarizes the GaN HEMT performance compared to prior 140-nm gate length GaN HEMTs used in previous linear distributed amplifiers. The MMICs shown in Figures 2(a) and 3(a) were fabricated in a microstrip layout with 2-mm-thick SiC substrate and via source contacts, SiN_x and HfO_2 MIM capacitors. TaN resistors were used in MMIC fabrication.

Measured GaN MMIC Performance

To maximize PAE over the frequency band, the GaN NDPAs were built in six sections with different transistor sizes, ranging from 6 x 85 µm to 2 x 65 µm in a nonuniform distributed amplifier approach.

Figure 2(a) shows a photograph of the fabricated GaN linear NDPA, consisting of main and auxiliary cells in each section, where the auxiliary cells were biased in class-C to cancel in-band intermodulation products such as IM3. Figure 2(b) shows measured on-wafer S-parameters at Vds = 20 V with a small signal gain of >10 dB over 0.1 – 8 GHz, a more than 6 – 9 dB improvement over the prior linear NDPA [10].

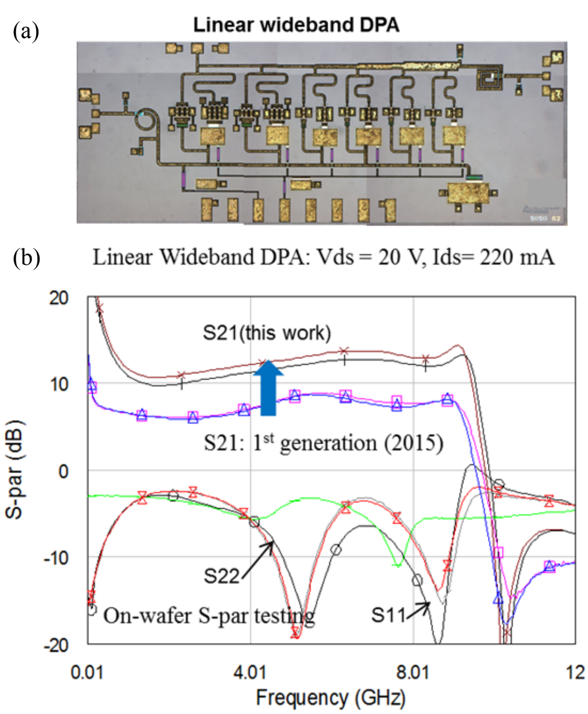


Figure 2. (a) Photograph of the fabricated GaN NDPA, (b) Measured on-wafer S-parameters at Vds = 20 V and Ids = 220 mA

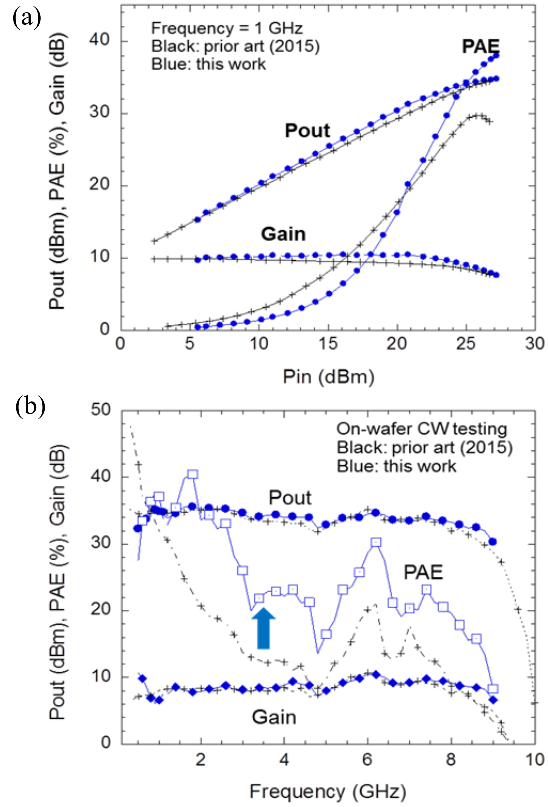


Figure 3. Measured on-wafer large-signal CW performance of GaN linear NDPA at Vds = 17 V at (a) 1 GHz and (b) as a function of frequencies, in comparison to the prior linear NDPA large-signal performance

Figure 3 shows the measured on-wafer, large-signal CW performance at Vds = 17 V at 1 GHz compared to prior linear NDPA large-signal performance. Peak PAE improved to 38% with drain efficiency (DE) of 45%, compared to a prior PAE of 29% and DE of 35%. Output power was similar, at ~35 dBm, and associated power gain was 7.8 dB.

Linearity Improvement

We measured small-signal, two-tone spectra of the GaN NDPA and linear NDPA at Vd = 17 V versus frequency range of 100 MHz to 8 GHz. As shown in Figure 4, the linear NDPA showed OIP3 improved to 45 – 50 dBm with an average of 47 dBm within 100 MHz to 6 GHz, compared to OIP3 of 42 dBm for the conventional NDPA without linearization. The resulting maximum OIP3/Pdc was 14:1. Green et al., reported GaN NDPAs with OIP3 of 43 dBm [2]. Kobayashi reported excellent OIP3 of 51 dBm over a 3-GHz bandwidth, where a cascode feedback design was used with high-voltage operation of 40 V [9]. The OIP3/Pdc was 5.2:1, which consumed about 30 W.

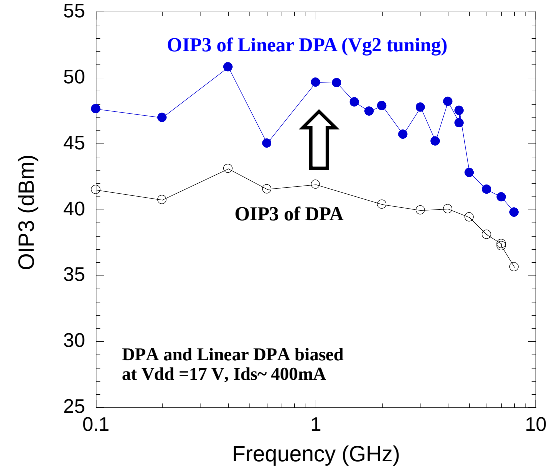


Figure 4. Measured 2-tone OIP3 performance of linear GaN DPA and a conventional GaN DPA over frequency range of 100 MHz to 8 GHz

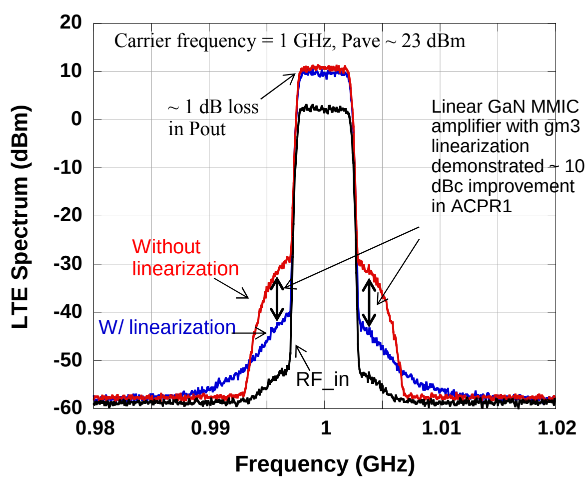


Figure 5. 5MHz QPSK LTE spectra of NDPA and linear NDPA at 17 V with average output power of 23 dBm

Figure 5 shows the 5 MHz QPSK LTE spectra of the conventional NDPA and linear NDPA at Vdd = 17 V. The spectral regrowh was evaluated with ACPR1. At an average output power of 23 dBm, the linear NDPA offers ~10 dB improvement in ACPR1 at 5 MHz offset, compared to the conventional NDPA.

Conclusion

Utilizing a 120-nm gate length field-plate GaN HEMT MMICs process, we demonstrated 0.1 – 8 GHz linear distributed amplifiers at the MMIC level with improved PAE. Two-tone testing showed excellent OIP3/Pdc ratio of ~14 among GaN distributed amplifiers. For the first time, a ACPR1 of -40 dBc was demonstrated at an average output power of 28 dBm over a wide frequency range.

Acknowledgement

This material is based upon work supported by the Office of Naval Research (ONR) under contract number N00014-14-C-0140, which was monitored by Dr. Paul Maki. The views expressed are those of the author and do not reflect the official policy or position of the Office of Naval Research (ONR) or the U.S. Government.

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